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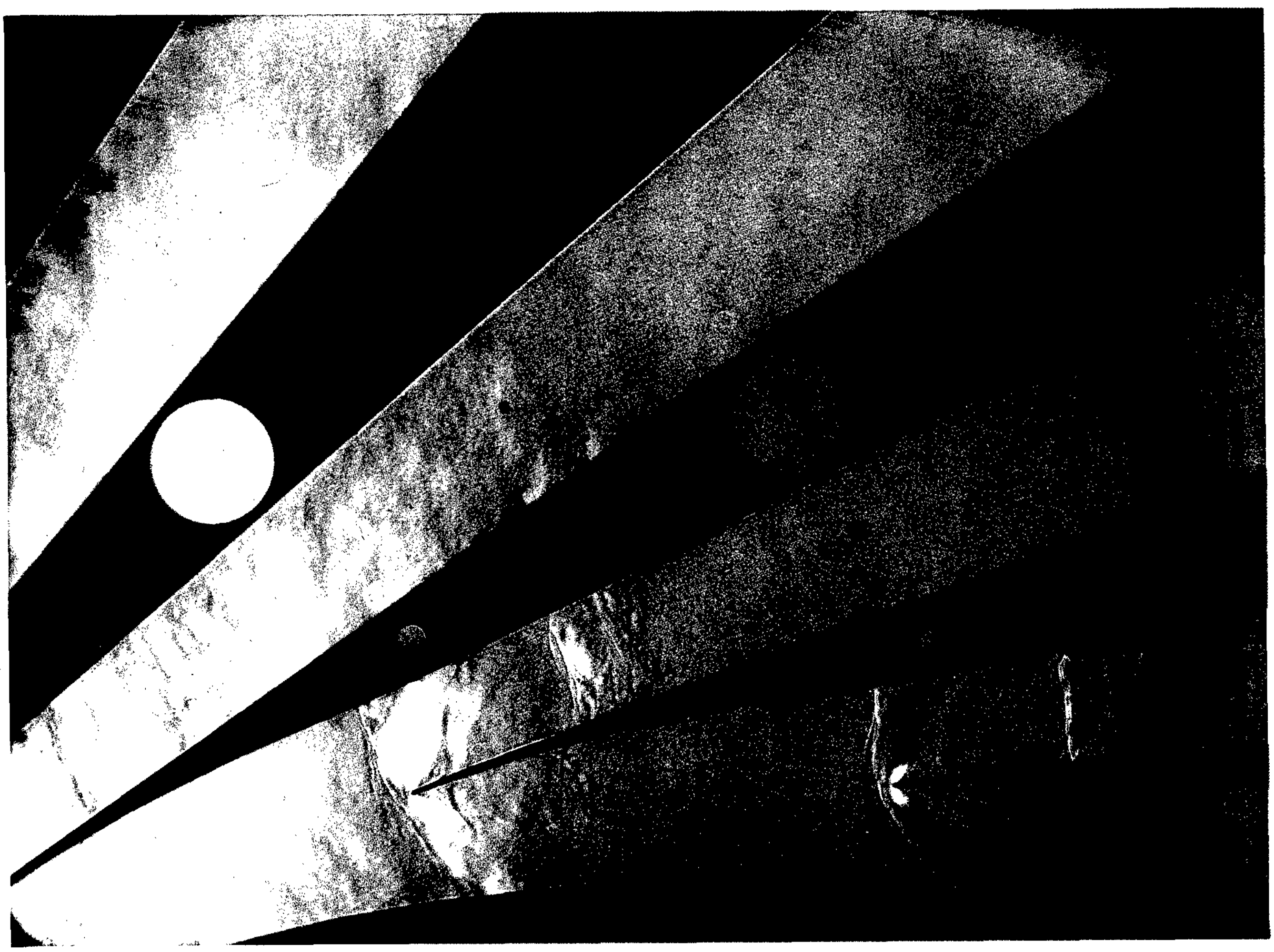
Microphysical and electrical modeling
of convective clouds



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Microphysical and electrical modeling of convective clouds

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RESUME D'AUTEUR :

A convective cloud modeling, "FILIGREE", has been modified and improved to take into account the "warm microphysics" phenomenon and the effect of lightning on the electrical evolution of the cloud. Good reconstructions of two storms observed in Florida in 1992 have been obtained with this model.

A kinematical version of FILIGREE has been realized and applied to the 14th of August 1992 storm.

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1. INTRODUCTION

Numerical modeling of convective clouds, especially of severe storms, are used to retrieve the dynamical, microphysical and, for some models, electrical behaviors of storm cells. The main inputs of these models are the thermodynamical state of the atmosphere before the clouds develop (temperature and humidity from the ground to the tropopause), and some regional meteorological features. They are used to improve our understanding of the cloud development, and of the effects of some phenomenon on this development. Numerous observations can be used to validate these reconstructions: radar survey of the cloud top and base heights, rate of precipitation, tracking of the electrical activity.

Since november 1992, we use a axi-symmetric dynamical cloud model, "FILIGREE" ([1], [2], [3], [4], [5]), developed by the Atmospheric Research Group of the Washington University (Seattle, USA). The first goal of this project was to apply this model to the reconstruction of two storms observed in 1992 in Florida (Orlando, USA) with meteorological radars (including velocity measurements by Doppler effect) and with an ONERA 3D VHF interferometer which provides the location of lightning discharges. This goal has required the improvement of the microphysical and electrification parametrization, to take into account the warm cloud microphysics, which are very important in tropical and semi-tropical storms such as those in Florida, and the dissipation of electric charges by lightning.

The second goal was to modify this model "FILIGREE" to a kinematical form, in order to use observed wind fields as an input, and to use this new version to retrieve the characteristics of the observed storms (14 and 17 August 1992 in Orlando).

This work has been done in collaboration with Robert Solomon (University of Washington, Seattle, USA) during his six weeks stay in our lab. This document is the final report of a contract under EOARD order n° F61 70894W0615 of June 28th, 1994.

2. IMPROVEMENTS OF THE MICROPHYSICAL AND ELECTRIFICATION PARAMETRIZATION

The more recent version of the cloud modeling FILIGREE has been implemented on ONERA's computer in January, 1995. It takes into account the "warm microphysics", that is the microphysical phenomenon associated with precipitation forming at temperatures warmer than 0 °C. These phenomenon are the melting of ice particles (ice crystals, hailstones), the breakdown of big drops into droplets, the conversion of droplets into bigger drops, and the multiplication of small splinters of ice by the Hallett-Mossop process (rapid freezing of supercooled drops after a collision with an ice crystal).

To represent the effect of old mature storm cells on a new one growing, we can introduce in our model a "seeding effect": the new cell develops in an atmosphere polluted by small ice crystals, and the concentrations of these crystals, varying with the altitude, are obtained from a previous modeling of the same storm.

In this new version of the FILIGREE model, the parametrization of the electrification has also been changed. In the older version, electrical charges appearance on ice particles was calculated using a parametrization, given in [6], of charge separation when an ice crystal rebounds on a graupel. This parametrization was based on many laboratory experiments, in various conditions of temperature and supercooled water content. In low water content conditions, this parametrization predicts very high charging rates of ice particles; this phenomena is now disputed, and it has been removed in the new version of our model.

When the electrical organization of the storm is established, at some altitudes the electrical field can reach a threshold corresponding to the beginning of the production of lightning discharges. These discharges will dissipate the electrical charges in the cloud, and thus reduce the electrical field. During his stay in our laboratory, R. Solomon introduced in the FILIGREE model a lightning parametrization, which provides the time evolution of the lightning rate, and of the length and altitude reach by these lightning discharges (intra-cloud and cloud-to-ground discharges). The lightning parametrization is one-dimensional and based on the work of Mazur and Runke, [7]. The lightning channel is considered to be a conducting channel in a non-uniform electric field. Every time a discharge is produced, electrical charges are induced on the surface of the lightning channel, and these charges are redistributed on ice particles, depending on their altitude and size.

3. RECONSTRUCTIONS OBTAINED

First, we have reconstructed the two storms (14th and 17th of August 1992) without any lightning parametrization. The observations have shown that the convective available potential energy was higher on the 14th of August than on the 17th, and that the electrification of this first storm was also higher.

The results of the model for the 17th show a very weak electrification, and a low convective dynamics, both consistent with the low activity observed. The reconstructions of the 14th of August exhibit a stronger convective dynamics, with vertical velocity up to 19 ms^{-1} (maximum velocity observed: 22 ms^{-1}). The calculated radar reflectivity reaches 61 dBZ (the observed value has hardly exceeded 60 dBZ), the maximum rain rate is 15 mm/h. The maximum electrical charges concentrations that we obtain are - 20 nCm^{-3} and + 28 nCm^{-3}, consistent with many measurements in storm clouds. The modeled distribution of electrical charges in the cloud have the typical dipole shape, with a main negative center between 5 and 7 km and a main positive center between 7 and 8,3 km (actually reaching the top of the cloud, at 15 km, but with a low charge concentration).

In order to compare the time evolution of the observed and reconstructed storm cells, we use the instant when the reflectivity reaches 15 dBZ to synchronise these evolutions. The retrieved precipitation arrives at the ground level 13 min after this time (observed value: 9,5 min). The maximum concentration of calculated electrical charge is found after 14,3 min, and the actual lightning activity of the observed cell has begun after 15 min.

When the lightning parametrization is used, the model calculates a lightning activity that begins after 6 min, and the lightning rate reaches quickly 40 flashes/min (observed value: 25 flashes/min), and decreases sharply after. This very first parametrization has to be improved, and especially the chosen threshold of the electrical field used to produce a discharge has a large effect on the time evolution and flash rate.

4. TRANSFORMATION TO A KINEMATICAL MODEL

Thanks to a three Doppler radars system, a three-dimensional reconstruction of the wind field is available every three minutes for the 14th and 17th of August storms. A sampling of this field along vertical lines in a given cell can be used as an input of a kinematical cloud modeling. A new kinematical version of FILIGREE, FILLY, has been realized : every time step of the reconstruction (usually every 4 s), the calculated vertical wind field is replaced by an interpolation of the observed wind field (avalailable every 3 min). The mass conservation equation gives the radial wind, in our simple model geometry (axi-symmetric), and the wind field is then used to advect all the other quantities (turbulent and thermodynamical energies, microphysical particles and their electrical charges, etc.).

This convective cloud model FILLY has been used to reconstruct the 14th of August storm. Two different wind fields can be used, sampled in two different cells: one cell formed in the peripheral region of the storm complex, and the other cell formed in the center of this complex. The modeled clouds contain very few ice, the maximum reflectivities reach 38 dBZ, and the charge concentration stays low. These values are increased (reflectivity reaches 50 dBZ) if we use the "seeding effect": the small ice concentrations calculated after a 4000 s reconstruction of one cell (formed at the periphery of the complex) is used as an input for the reconstruction of a new cell (formed in the center of the complex).

The results given by this model are not yet satisfactory, compared to the ones given by FILIGREE. This model must be improved by the addition of the "warm microphysics" processes, and by using a better interpolation of the wind fields.

5. CONCLUSION

This collaborative project with the Washington University, and especially the stay of Robert Solomon in our lab for six weeks, allows us to obtain good reconstructions of the two storms observed in Orlando (Florida, USA; 14th and 17th of August 1992) with the cloud model FILIGREE, including new microphysical processes and a modified electrification parametrization. These reconstructions exhibit a better representation of liquid water behavior, and a higher electrical charging rate. A lightning parametrization has been included in this model, to estimate the rate and altitude reach by the lightning flashes; we have started its conversion to a kinematical version, that will be modified by the inclusion of the "warm microphysics" processes, and a new interpolation of the observed wind field. This fruitful collaboration will be continued, in order to apply these cloud model to new storms observed in Florida (1993) and New Mexico (1994), and to compare the radar and lightning three-dimensional observations with our reconstructions. These reconstructions will be used to improve our understanding of the behavior and evolution of severe storms, that can have dramatic effects on the air traffic.

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